# A Scheduling System and Method for Avoiding Low Equipment Utilization

## Background of the Invention

### Field of the Invention

[0001] This invention relates generally to a computer integrated manufacturing systems and methods. More particularly, this invention relates to computer integrated manufacturing systems and methods for scheduling dispatching of lots of product to units of manufacturing equipment for fabrication. Even more particularly, this invention relates to computer integrated manufacturing systems and methods for dispatching lots of product with high priority while avoiding low utilization of the units of manufacturing equipment.

### Description of Related Art

[0002] In firms such as semiconductor fabrication companies commonly referred to as silicon foundries, there are numerous factories at various locations. Each of the factories may have multiple fabrication lines, employing different sets of processing equipment. Currently most fabrication lines are highly automated and controlled by computer integrated manufacturing systems (CIM). The CIM system receives dispatch scheduling information regarding the product to be manufactured from a marketing and sales database. From the dispatch scheduling information, the CIM schedules the necessary processing equipment

and distribution of the raw materials. The CIM then starts the manufacturing process and provides monitoring of the processing equipment.

[0003] Certain customers of a manufacturing enterprise negotiate higher priority for fabrication of certain lots of product. Or committed schedule may require that certain lots of product must be granted a higher priority. These priorities are commonly referred to as "Hot Lots" or "Super Hot Lots" and require that their progress through a manufacturing facility be unimpeded. Often this requires that lots having a normal priority be held up as soon as a "Super Hot Lot" is scheduled for dispatch to a unit of manufacturing equipment. Refer now to Fig. 1 for a discussion of the dispatch and scheduling of lots of product within a manufacturing facility. The manufacturing facility, as illustrated, is a semiconductor foundry which processes lots of substrates wafers **10** and **20**. The units of manufacturing equipment **5** and **50** are such equipment as etchers, diffusion ovens, sputtering deposition units, etc. The normal lots of substrates **20** are processed by the first unit of manufacturing equipment (i.e. a substrate surface cleaning unit) **5** and transferred **30** the normal lots to a queuing area **25** awaiting processing by a second unit of manufacturing equipment (i.e. a sputtering unit) **20**. However, if a "Super Hot Lot" of product lot 10 arrives for processing at the first unit of manufacturing equipment **5**, the operator **15** must restrict the transfer of the normal lots **20** to the second unit of manufacturing equipment **50**. The second unit of equipment **50** then remains idle until the operator **15** receives **35** the "Super Hot Lot" of product **10** from the first unit of manufacturing equipment **5**. The operator then places **45** the "Super Hot Lot" of

product **10** in the second unit of manufacturing equipment **50** for processing. The normal lots of product **20** have now been idle while the "Super Hot Lot" of product **10** is in transit and in the second unit of manufacturing equipment **50**.

[0004] Refer now to Fig. 2 for a discussion of the utilization rate of the scheduling of the "Super Hot Lot" of product **10** of Fig. 1. At the notification **100** of that the "Super Hot Lot" of product **10** is being dispatched. The second unit of manufacturing equipment is set to idle and the normal priority lots are waiting **105**. In this example, the waiting time **110** is for 30 minutes. At the arrival of the "Super Hot Lot" of product **10**, the second unit of manufacturing equipment processes the "Super Hot Lot" of product **10** for 46 minutes **120**. Further, in this example, the next lot of product to be processed is placed in the second unit of manufacturing equipment approximately six minutes prior to the exit of the previous lot of product, in this example the "Super Hot Lot" of product **10**. Thus the time for processing the next lot of product, which is 46 minutes, overlaps the processing of the "Super Hot Lot" of product **10** and therefore the elapsed time **130** of the next lot is 40 minutes. Similarly, the second normal lot **135** is placed in the second unit of manufacturing equipment six minutes prior to the ending of the first normal lot **125**. The elapsed time **140** of the second normal lot of product is also 40 minutes.

[0005] The total time **145** for processing the three lots of product is 156 minutes. Each lot of product contains 25 wafer substrates, therefore 75 wafers are processed in the 156 minutes. It can be shown that the utilization rate is 126/156

or 80.76% and that the throughput is 28 wafers per hour (75 wafers/(156minutes/60minutes)).

[0006] U. S. Patent 5,818,716 (Chin, et al.) describes a dispatching algorithm for a semiconductor manufacturing fabrication plant with production to-order type operation. The dispatching algorithm functions according to the level of current wafers in process (WIP). The dispatching algorithm revises the due date for every lot to satisfy the demand from Master Production Scheduling (MPS). Further the dispatching algorithm calculates the required turn rate of each lot based on process flow to fulfill the delivery requirement. The dispatching algorithm determines not only due date and production priority of each lot, but also provides required turn rate for local dispatching. The local dispatching systems of each working area dispatch the lots by using required turn rate to maximize output and machines utilization.

[0007] U. S. Patent 5,737,728 (Sisley, et al.) illustrates a system and method for assigning and scheduling resource requests to resource providers using a modified "best-first" search technique that combines optimization, artificial intelligence, and constraint-processing to arrive at near-optimal assignment and scheduling solutions. In response to changes in a dynamic resource environment, potential changes to an existing assignment set are evaluated in a search for a better solution. New calls are assigned and scheduled as they are received, and the assignment set is readjusted as the field service environment changes, resulting in global optimization. Each search operation is in response

to either an incremental change to the assignment set such as adding a new resource request, removing a pending resource request, reassigning a pending resource request, or to a request for further evaluation. Thus, the search technique assumes that the existing assignment set is already optimized, and limits the task only to evaluating the effects of the incremental change. In addition, each search operation produces a complete assignment and scheduling solution. Consequently, the search can be terminated to accept the best solution generated so far, making the technique an "anytime" search.

[0008] U. S. Patent 5,548,518 (Dietrich, et al.) teaches a novel allocation method for generating a feasible production schedule. The method, in response to a specified requirement first determines what quantity of a product can be produced with a specified quantity of supply components. The method then allocates a required quantity of supply components for filling a thus defined partial order; and then fills a remainder of the requirement at some later time.

[0009] U. S. Patent 5,291,394 (Chapman) describes a system and process for allowing virtual allocations of resources to lots to closely mimic actual allocations of resources to lots. Virtual allocations represent planned or scheduled allocations of an organization's resources to produce various products. Actual allocations represent the actual course of events which occur while the product is being manufactured. A manufacturing interpreter interactively functions with an expert in a manufacturing environment to produce a comprehensive and accurate definition of resources utilized in a manufacturing environment. The

manufacturing interpreter further allows the expert to define a comprehensive and accurate process flow description for various products. The process flow description specifies the resources, resource attribute capabilities, and order for applying resources to a single lot to produce a completed product. A planner operates upon this process flow data to generate a processing plan that is specifically adapted for the organization at a particular point in time, and an execution controller utilizes the processing plan to control the manufacturing of products within the manufacturing environment. Operation of the execution controller keeps allocation data current. Thus, the planner has current allocation data with which to merge process flow data for new products.

[0010] U. S. Patent 5,040,123 (Barber, et al.) illustrates an expert system scheduler that uses heuristics developed by an experienced factory scheduler. The scheduler uses these heuristics to generate schedules. Forward and backward scheduling is used at different stages of the schedule generation process.

[0011] U. S. Patent 5,841,677 (Yang, et al.) details a lot dispatching method and apparatus for dispatching WIP lots in the manufacture of semiconductor integrated circuits. The method includes determining an average process time and average number of lots per batch of a succeeding process, and determining allowable lots of a preceding process. The allowable lots is equal to the preceding lots undergoing the preceding process to the extent that the sum of and the lots waiting to undergo the succeeding process is not greater than the

maximum batch size of the succeeding process. An allowable waiting time is then determined in accordance with a lot waiting rule, where the allowable waiting time represents the average time for processing the number of additional lots to be gained by waiting for the preceding process to complete. If the expected waiting time for the preceding process to complete is greater than the determined allowable waiting time, the WIP lots are immediately processed in the succeeding process; otherwise, the WIP lots are not dispatched until the allowable lots of the preceding process arrive, which are then combined into a single batch and dispatched into the succeeding process.

## Summary of the Invention

[0012] An object of this invention is to provide a manufacturing equipment scheduler that controls the run sequences of product lots to minimize low utilization rates of units of manufacturing equipment within a manufacturing facility.

[0013] In order to accomplish at least this object, a manufacturing equipment scheduling system includes a product lot sequence controller. The product lot sequence controller is in communication with a product lot dispatch system to receive priority information of the product lots dispatched for fabrication. The product lot sequence controller is further in communication with an operations controller to establish an order in which the product lots are processed by units of the processing equipment. The product lot sequence controller establishes the order by first receiving a dispatch order for at least one current product lot. The

product lot sequence controller then determining a priority of the current product lot. If the current product lot has a high priority, the product lot sequence controller then determines if a previous product lot remains in a selected unit of processing equipment. If the previous product lot is remaining in the selected unit processing equipment, the product lot sequence controller determines if the previous product lot is has a normal priority. If the previous product lot has a normal priority, the product lot is removed from the selected unit of processing equipment and the product lot with the high priority is processed. Upon completion of processing the current product lot with high priority, processing for the previous product lot is continued.

[0014] The product lot sequence controller further establishing the order by determining if the previous product lot remains in the selected unit of processing equipment, if the current product lot has the normal priority. If the previous product lot is remaining in the selected unit of processing equipment, the processing of the previous product lot continues to completion. Upon completion of the previous product lot, the processing the current product lot with the normal priority is initiated.

[0015] The product lot sequence controller further establishes the order by determining if the previous product lot remains in the selected unit of processing equipment, if the current product lot has the high priority. If the previous product lot is remaining in the selected unit of processing equipment has a high priority, continuing processing the previous product to completion. Upon completion of

processing the previous product lot, processing the current product lot with the high priority.

[0016] The removing the previous product lot from the selected unit of processing equipment begins by commanding the selected unit of processing to cease processing the previous lot. The status information of all pieces of product within the product lot is recorded. The selected unit of processing equipment is then instructed to return the previous product lot to a staging location.

[0017] The continuing processing of the previous product begins by examining status information of all pieces of product within the product lot. The selected unit of processing equipment is instructed to acquire the previous product lot from the staging location and then commanded to continue processing the previous lot.

[0018] The manufacturing equipment scheduling system further includes a messaging facility. The messaging facility is connected to communicate messages between the product lot sequence controller, the units of the processing equipment, and product lot dispatch system.

[0019] In an embodiment of this invention, the product lots are integrated circuit substrates or wafers and the units of the processing equipment are integrated circuit fabrication equipment.

## Brief Description of the Drawings

[0020] Fig1 is a diagram illustrating the flow of lots of product between units of manufacturing processing equipment illustrating the handling lots having high priority of the prior art.

[0021] Fig. 2 is timing diagram illustrating the utilization of a unit of manufacturing processing equipment in processing lots of product with high priority.

[0022] Fig. 3 is diagram of a manufacturing facility having a scheduling and dispatch system for controlling run sequences of product lots to minimize low utilization rates of units of manufacturing processing equipment of this invention.

[0023] Fig 4 is a diagram illustrating the flow of lots of product between units of manufacturing processing equipment illustrating the handling lots having high priority of this invention.

[0024] Fig. 5 is timing diagram illustrating the utilization of a unit of manufacturing processing equipment in processing lots of product with high priority by controlling run sequences of product lots to minimize low utilization rates of units of manufacturing processing equipment of this invention.

[0025] Figs. 6 and 7 are flow diagrams for a process executed by a software agent for controlling run sequences of product lots to minimize low utilization rates of units of manufacturing processing equipment of this invention.

## Detailed Description of the Invention

[0026] A scheduling and dispatch controller of a computer integrated manufacturing system executes a program or software agent that schedules manufacturing equipment to control run sequences of product lots to minimize low utilization rates of units of manufacturing processing equipment employed in fabricating the product lots. The program process executed by the software agent begins by communicating with a product lot dispatch system to receive priority information of the product lots dispatched for fabrication and communicating with an operations controller to establish an order in which the product lots are processed by units of the processing equipment. The order of the product lots in processing is established by receiving a dispatch order a current product lot with its priority. If the current product lot has a high priority, it must be determined whether a previous product lot remains in a unit of processing equipment. It there is a previous product lot remaining in the unit of processing equipment, it must be determined whether the previous product lot is has a normal priority. If the previous product lot has a normal priority, the previous product lot is removed from the selected unit of processing equipment and the current high priority product lot is processed. Upon completion of processing the current high priority product lot, the unit of manufacturing processing equipment continues processing the previous normal priority product lot to completion.

[0027] Refer to Fig. 3 for a description of the computer integrated manufacturing system having the program or software agent that schedules manufacturing equipment to control run sequences of product lots to minimize low utilization rates of units of manufacturing processing equipment employed in fabricating the product lots. The manufacturing production area **200** has multiple units of manufacturing equipment **205a**, ...., **205n** which perform the processing steps of the recipes for each stage of the procedures for processing a lot of manufactured product lots. In an integrated circuit fabrication facility or silicon foundry, the units of manufacturing equipment **205a**, ...., **205n** are etchers, diffusion oven, sputtering deposition units, substrate surface cleaning units, etc.

[0028] The multiple units of manufacturing equipment **205a**, ...., **205n** are each connected to a manufacturing execution system operator console **210a**, ...., **210n**. The manufacturing execution system operator console **210a**, ...., **210n** is connected to receive sensor information describing the operation status of each of the multiple units of manufacturing equipment **205a**, ...., **205n** and to transmit necessary operation control commands to each of the multiple units of manufacturing equipment **205a**, ...., **205n**. An operator monitors each of the manufacturing execution system operator consoles **210a**, ...., **210n** to coordinate the function of each of the multiple units of manufacturing equipment **205a**, ...., **205n**. The manufacturing execution system operator consoles **210a**, ...., **210n** are connected with the messaging network **230** to communicate with the computer integrated manufacturing system (CIM) **235**. The CIM system **235** is retrieves the necessary process instruction from the process database **250** and

the equipment allocations and locations from the equipment database **245**. When an order for product is recorded in the marketing and sales database **240**, the CIM system **235** is alerted to the order. The order includes a committed delivery schedule and any committed priority that is granted to the customer. The CIM system **235** separates the order into the number of manufacturing product lots required in the fabrication of the product. The CIM system **235** then assigns a priority to each of the manufacturing product lots. The manufacturing product lots **220a**, ...., **220n**, and **225** are then dispatched to the manufacturing production area **200**. Those manufacturing product lots **220a**, ...., **220n** that are committed to delivery in a time that allows for normal processing through the manufacturing production area **200** are assigned a normal priority. Alternately, those manufacturing product lots **225** that require immediate processing are assigned a hot or super hot priority.

[0029] The CIM system **235** provides a scheduling and dispatch function that determines the allocation of the manufacturing product lots **220a**, ...., **220n**, and **225** to the multiple units of manufacturing equipment **205a**, ...., **205n**. Further the scheduling and dispatch function acts to coordinate the manufacturing execution system operator consoles **210a**, ...., **210n** to insure maximum utilization of the multiple units of manufacturing equipment **205a**, ...., **205n**.

[0030] The CIM system **235** communicates, as shown in Fig. 4, a priority control agent or program **260** that controls run sequences of product lots to minimize low utilization rates of units of manufacturing processing equipment **205i** and **205j**.

Under normal operation, the manufacturing product lots **220a**, ...., **220n** are transferred **265** from a previous unit of the manufacturing equipment **205i**, upon completion of processing, to the staging area or normal lot waiting area **255**. The normal lot waiting area **255** is the location from which the operator **215i** retrieves a next manufacturing product lot **220a**, ...., **220n** that is to be processed by the current unit of the manufacturing equipment **205j**. If the manufacturing execution system operator console **210i** receives notification of the arrival of a high priority or super hot product lot **225** by way of the priority control agent **260**, the operator begins processing next the manufacturing product lots **220a**, ...., **220n**. When the super hot manufacturing product lot **225** arrives, the operator verifies the priority of the previous manufacturing product lot **220a**, ...., **220n** placed in the unit of manufacturing equipment **205j**. If the previous manufacturing product lot **220a**, ...., **220n** has normal priority, the previous manufacturing product lot **220a**, ...., **220n** is removed from the multiple units of manufacturing equipment **205j** and the super hot lot manufacturing product lot **225** is processed. Upon completion of the processing of the super hot lot manufacturing product lot **225**, the previous manufacturing product lot **220a**, ...., **220n** is replaced in the current unit of manufacturing equipment **205j** to complete processing. Of course, it is obvious to one skilled in the art, that the processing of the previous manufacturing product lot **220a**, ...., **220n** must have a recipe that allows for interruption during the execution of the steps of the recipe. This would be, for instance, in a semiconductor foundry, where a sputtering unit operates on each individual wafer. Thus, at the completion of the sputtering process on an

individual wafer, the lot being processed maybe removed from the sputtering unit and placed in a staging area waiting completion of the process. When the super hot lot of wafers is complete, the previous lot of wafers may be returned to the sputtering unit for completion of the processing of the wafers in the lot.

[0031] The advantage of the run sequence agent that controls the order and interruption of the processing of manufacturing product lots is shown in Fig. 5. At the time **300** the manufacturing execution system operator console is alerted by the CIM system that a super hot lot manufacturing product lot is being processed by a previous unit of manufacturing equipment, rather than holding the current unit of manufacturing equipment idle until the super hot manufacturing product lot arrives. The operator will initiate the processing **305a** of a normal manufacturing product lot. The time **310** between the announcing the presence of a super hot manufacturing product lot and its arrival at the current unit of manufacturing equipment is 30 minutes in this example. The processing time of the previous manufacturing product lot is scheduled to be 46 minutes, however, the processing is suspended and the previous manufacturing product lot is removed from the unit of manufacturing equipment. The super hot manufacturing product lot is placed in the current unit of manufacturing equipment to begin processing **315** at the time **340** for a period of 46 minutes. The previous manufacturing product lot is placed in a staging area awaiting resumption of processing for the remaining time period **345** (16 minutes). At the completion of the processing of the super hot lot manufacturing product lot, the processing **305b** of the normal manufacturing product lot resumes at the time **350** and requires the sixteen

minutes **355** for the completion of the previous manufacturing product lot. As described above, an overlap of time wherein a next manufacturing product lot is placed in the current unit of manufacturing equipment and the previous manufacturing product lot is removed. The second normal manufacturing product lot is placed in the unit of manufacturing equipment and processing is begun **325**. The previous manufacturing product lot is removed, the next manufacturing product lot continues, and at a time 40 minutes later **330** the next manufacturing product lot is completed. Thus there are 75 wafers of the product lot completed in 132 minutes. With the message alerting to the arrival of the super hot lot manufacturing product lot and the partial processing of the previous manufacturing product lot the utilization is effectively 100% for an increase in utilization of 19.2% over the example of the prior art. Further, the processing rate can be shown to be more than 34 wafers per hour. This is an increase in production rate of more than six wafers per hour over the prior art.

[0032] The manufacturing equipment scheduling sub-system of the CIM system provides the software agent that performs the function of the product lot sequence controller. The software agent is retained by a data retention device and when extracted by a computer of the CIM system, performs a program process that is described in Figs. 6 and 7. The CIM system dispatches (Box **400**) manufacturing product lots and the software agent as executed on the manufacturing execution system operator console examines (Box **405**) the priority of the dispatched lots to determine whether the manufacturing product lot has a high priority. The software agent then examines (Box **410**) the contents of

the unit of manufacturing equipment to determine if a previous manufacturing product lot is still in process. If there is a previous manufacturing product lot in the unit of manufacturing equipment, the previous manufacturing product lot is completed (Box **420**) and the currently dispatched normal manufacturing product lot is then processed (Box **440**). Alternately, if there is no previous manufacturing product lot in the unit of manufacturing equipment, the currently dispatched normal manufacturing product lot is then processed (Box **440**).

[0033] If the dispatched lot is determined (Box **405**) to be a high priority or super hot lot, the software agent then determines (Box **415**) if the unit of manufacturing equipment contains a previous manufacturing product lot. If the unit of manufacturing equipment does not contain a manufacturing product lot, the currently dispatched super hot lot manufacturing product lot is processed (Box **440**). Alternately, if the unit of manufacturing equipment does contain a previous manufacturing product lot, the software agent must determine (Box **425**) whether the previous manufacturing product lot has a high priority or is super hot. If the previous manufacturing product lot is super hot, the previous manufacturing product lot is processing is completed (Box **430**). If the previous manufacturing product lot is not super hot and has a normal priority, processing of the previous manufacturing product lot is stopped (Box **435**) and the previous manufacturing product lot is removed from the unit of manufacturing equipment and the super hot lot manufacturing product lot is processed (Box **440**). Referring to Fig. 6, the stopping of the previous manufacturing product lot requires that the software agent command the unit of manufacturing equipment to cease processing of the

previous manufacturing product lot. The run status information is then recorded and the previous manufacturing product lot (wafers in the silicon foundry example) is returned to the staging area.

[0034] Upon completion of processing (Box **440**) the currently dispatched lot, the software agent must determine (Box **445**) if the previous lot has competed processing. If the previous lot has not completed processing, as in the instance of the super hot lot processing, upon completion of processing (Box **440**) of the currently dispatched manufacturing product lot, the currently dispatched manufacturing product lot is transferred (Box **450**) to the next stage of the processing and the previous manufacturing product resumes processing (Box **455**). Referring to Fig. 7, the resumption of the processing (Box **455**) of the previous manufacturing product lot is accomplished by reading the run status information for all the product units (wafers) within the previous manufacturing product lot and then commanding the unit of manufacturing equipment to resume processing of all unfinished product units or product units that have not been processed.

[0035] Upon completion of the processing of the previous manufacturing product lot or if there is no previous manufacturing product lot, the manufacturing product lot completing processing is transferred (Box **460**) to the next unit of manufacturing equipment. The action of the software agent is completed and returns (Box **465**) to monitor the next manufacturing product lot dispatch.

[0036] The manufacturing equipment scheduling system of this invention employs a product lot sequence controller to avoid low utilization rates of the unit of manufacturing equipment, while reducing the cycle times for normal manufacturing product lots and minimizing excessive idle time. Further, when an operator mistakenly begins processing a normal manufacturing product lot when a super hot manufacturing product lot has arrived or is about to arrive, the product lot sequence controller controls which lots are processed. Processing of the previous normal manufacturing product lot is stopped and the super hot manufacturing product lot is processed. When the super hot manufacturing product lot is completed, the product lot sequence controller instructs the operator to complete the processing of the previous manufacturing product lot before starting the next normal manufacturing product lot.

[0037] While this invention has been particularly shown and described with reference to the preferred embodiments thereof, it will be understo product lot sequence controller product lot sequence controller od by those skilled in the art that various changes in form and details may be made without departing from the spirit and scope of the invention.

[0038] The invention claimed is: